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Heat Treatment Forming a Dissipative Metal Base in Wear-Resistant Chromium-Alloyed Cast Iron

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Abstract. The maximum abrasive wear resistance is provided by a metal base from metastable retained austenite and martensite. Such a microstructure of 260Kh16M2 and 250Kh25MFT chromium cast irons with different types of Cr_7C_3 and $Cr_{23}C_6$, carbides is created by high-temperature quenching with heating to temperatures of 1125-1170 °C and cooling in oil or air. Austenite is transformed to disperse martensite on the working surface as a result of the impact of abrasive particles during operation. Together with carbides, it provides a high hardening level and a high working capacity of the secondary microstructure of the cast irons.

INTRODUCTION

The structure of wear-resistant chromium-alloyed white cast iron consists of solid special carbides (usually not less than 20-30% of eutectic and secondary carbides) and a metal substrate, which must be hard and ensure good fixation of carbide particles. Required chromium content ensures special type carbides, Cr_7C_3 and $Cr_{23}C_6$. The most wear-resistant cast irons have an average carbon content of 2.3-2.7% and a chromium content of 12-18%, with carbides of the M_7C_3 type. In some cases, high-chromium cast iron with 23-28% of chromium is used, especially under conditions of abrasion-corrosion wear [1-3].

Austenite and products of its transformation make up the metallic matrix. Martensite and retained austenite are the most desirable to provide maximum wear resistance [1]. However, the ratio and chemical composition of these phases remain poorly understood.

The aim of this paper is to study the features of phase composition formation and the structure of the metal base of 260Kh16M2 and 250Kh25MFT with different types of carbides – M_7C_3 and $M_{23}C_6$. The heat treatment technology must provide maximum abrasive wear resistance for rapidly wearing parts (for example, for blades of shot blasting machines or end armor lining plates of ball mills).

MATERIALS AND METHODS OF RESEARCH

Cast iron is melted in an induction furnace. The samples were quenched in oil from heating temperatures of 900-1170 ºC. The gauge part of the samples was 10×10 mm for the microstructure study and abrasive wear tests. Some of the samples were cooled in air. The duration of holding at the heating temperature was 20 min. Samples of the 150KhNML pearlitic steel after quenching from 850 ºC in oil and 3-hour tempering at 200 ºC, with a hardness of 61 HRC, were used as a standard in the abrasion test.

The samples were reciprocated in a special installation at a specific load of 1 MPa on 14A32MN481 corundum-based grinding paper (GOST 6456-82) at a speed of 125 mm/s and a sample displacement in one double stroke of

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1.2 mm. The abrasive wear resistance was evaluated by the results of two parallel tests. A comparison of the results was carried out through relative units,

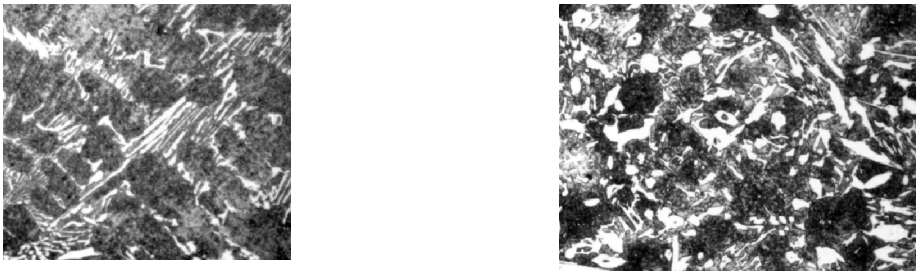
$$\varepsilon = \frac{\Delta M_{sm}}{\Delta M_{st}} \tag{1}$$

Here, ε is relative wear resistance, ΔM_{st} is the mass loss of the reference sample taken as unit, and M_{sm} is the weight loss of the test sample, which was less than 1% per friction path of 60 m. After wear, the phase composition of the sample surface was determined by X-ray diffraction analysis. The working surface hardening was estimated by the microhardness increment measured at a load of 0.49 N.

RESULTS AND DISCUSSION

The phase transformation analysis during the crystallization of 250Kh25MFT and 260Kh16M2 cast irons was carried out by vertical sections of the Fe-Cr-C ternary diagram [1] and metallographic and X-ray analysis data. The equilibrium structure is formed in process of cooling in molds. The structure is composed of ferrite and a mixture of $M_{23}C_6$ and $(Fe,Cr)_7C_3$ carbides in the 250Kh25MFT cast iron and carbides of the same type – $(Fe,Cr)_7C_3$ – in the 260Kh16M2 cast iron in the free state and/or constituent ferrite-carbide mix. The total amount of carbides is less in the cast iron with a lower chromium concentration (about 25%), and in the 250Kh25MFT cast iron – about 30%.

Retained austenite and martensite are present in both cast irons. A relatively larger amount of residual austenite was formed in the alloy with increased chromium content. This causes lower hardness of this alloy – 54 and 56 HRC, respectively. According to vertical sections of the ternary diagram in high-chromium white iron, the precipitation of secondary carbides precedes the formation of austenite transformation products in the supersaturated solid solution. The VC and TiC carbides are precipitated as the primary phase in the cast iron melt with small amounts of vanadium and titanium in the composition. Alloying of 1-2% molybdenum does not change the pattern of primary crystallization [1]. Ferrite in the free state or in the ferrite-carbide mix is an undesirable structural constituent for high wear resistance. It is necessary to propose heat treatment conditions for the cast irons under study which will provide the necessary phase composition of the metal base with a controlled amount of carbides, martensite and metastable austenite. Cast iron hardening from increased heating temperatures in oil or in a fan jet (in sections up to 30 mm) makes it possible to regulate the martensite and retained austenite ratio over a wide range. This ratio greatly affects its abrasive wear resistance. The microstructure of the 250Kh25MFT cast iron after quenching from different temperatures is shown in Fig. 1. Eutectic carbides have an elongated shape. The shape, size and distribution of carbides in the metal matrix are not uniform: most disperse carbides are globular-shaped, larger particles are with acute-angled edges, and there are needle-like carbide precipitates (Fig. 1). Large precipitations are primary carbides. The structure of the samples after normalization from 1040 °C does not differ from the structure of the cast metal. The metal matrix has cellular morphology with the precipitation of carbides both inside and outside the cell boundaries.

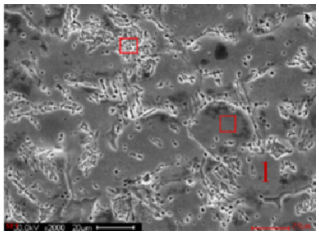


(a) (b)

FIGURE 1. The microstructure of the 250Kh25MFT cast iron: quenching from 900 °C (a), quenching from 1170 °C (b), ×200

The number of eutectic carbides remains unchanged as a result of the quenching temperature increase. It is of interest to increase the amount of retained metastable austenite. The study of the regulated structural factor – the chemical composition of the metal base of the alloys is possible by increasing the quenching temperature from 900 to 1170 ºC. The chromium concentration was close to 12% and 18% in the 260Kh16M2 and 250Kh25MFT cast

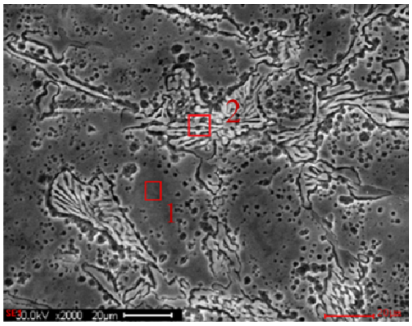
irons, respectively, in the solid solution, according to the data of micro-X-ray spectroscopy and X-ray diffraction analysis (Fig. 2).



(a)

Element	wt%	Area 1 at.%
Mo	02.05	01.19
Ti	00.66	00.76
V	00.66	00.72
Cr	11.12	11.92
Mn	00.76	00.77
Fe	84.76	84.63

(b)



(c)

Element	wt%	Area 1 at.%
Mo	00.82	00.48
Cr	17.59	18.37
Mn	02.57	02.60
Fe	85.02	84.55
Element	**wt%**	**Area 2 at.%**
Mo	04.46	02.56
Cr	43.12	45.69
Mn	02.77	02.78
Fe	49.65	48.97

(d)

FIGURE 2. The results of micro-X-ray spectral analysis: a – cast iron 260Kh16M2, quenching 1170 °C; c – cast iron 250Kh25MFT, quenching 1170 °C, b, d – chemical composition from isolated sections (1 – solid solution, 2 – eutectic carbides)

The carbon concentration in martensite, according to the micro-X-ray and X-ray diffraction analysis, was close to 0.6%. It correlates with the values obtained for cast iron 260kh16M3 by the calculation method [2].

The maximum wear resistance is obtained by high-temperature quenching. It is carried out to obtain a sufficient (over 50%) amount of retained metastable chromium austenite in the metal base, despite lower initial hardness in comparison with low-temperature quenching. It is characteristic in this case that the chemical composition of the metal base must have a carbon content of 0.6-0.7% and the corresponding combination of chromium and other alloying elements to ensure the condition 20 ºC < M_s, M_f > 20 ºC. Thus, martensite transformation develops mainly in the process of operation [2, 3]. A high level of hardening is not achieved due to the formation of strain-induced martensite with carbon content below 0.6%. The austenite becomes too stable relative to strain-induced martensitic transformation at carbon concentration exceeding 0.7% [2]. There is a good correlation of the maximum values of relative wear resistance with those of microhardness on the working surface after wear. The relationship between initial hardness and wear resistance is opposite. If the initial hardness after low-temperature hardening (900 °C) in the 260Kh16M2 and 250Kh25MFT cast irons is 65 and 62 HRC, and the wear resistance is 1.5 and 2.6, respectively, relative to the data for the 150KhNML hardened steel, then, after quenching from 1170 ºC, the initial hardness decreases to 46 and 56 HRC, and the wear resistance, on the contrary, increases to 2.8 and 3.5, respectively (Fig. 3).

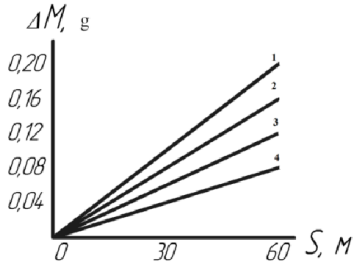


FIGURE 3. Mass loss on the friction path of cast irons: 1 – 260Kh16M2, quenching 900 ºC; 2 – 260Kh16M2, hardening 1170 ºC; 3 – 250Kh25MFT, hardening 900 ºC; 4 – 250Kh25MFT, hardening 1170 ºC

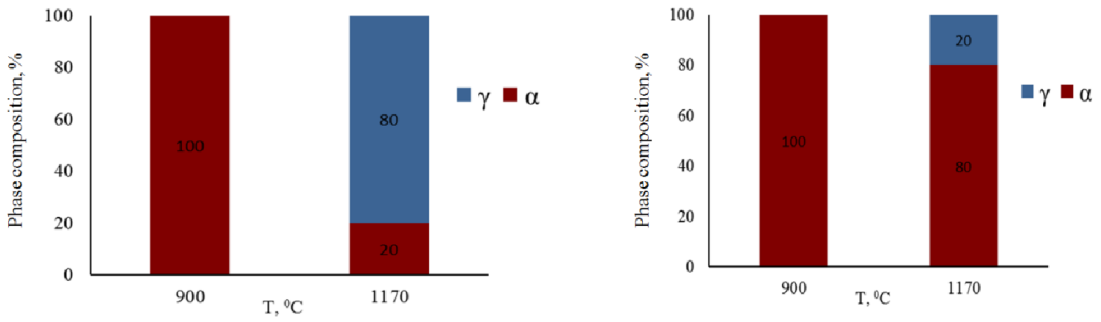


FIGURE 4. The matrix phase composition of the working surface of the 250Kh25MFT cast iron samples hardened from 900 ºC and 1170 ºC: a – before abrasive wear testing; b – after abrasive wear testing

Due to martensite formation under frictional action, the effective microhardness (microhardness on the working surface) increases to 11.5 GPa after high-temperature quenching, while it is 10-10.5 MPa after quenching from low temperatures. The higher the microhardness of the secondary structure of the surface, the smaller the volume of the metal participates in the creation of the working layer. This layer provides energy dissipation of the abrasive particles. Therefore, the separation of the wear particles occurs with a smaller (in depth) volume, and the abrasive wear resistance of the alloy is higher (Fig. 4). Higher austenitization temperature increases the degree of dissolution of special carbides and alloying of the solid solution with carbon, chromium and molybdenum. This leads to a decrease in the martensitic transformation temperature and to an increase in the amount of retained austenite, especially above the heating temperature of 1050 °C. Figure 3 shows the wear kinetics of the 260Kh16M2 and 250Kh25MFT cast iron samples. The advantage in the wear resistance of the 250Kh25MFT cast iron is maintained due to a higher carbide phase content.

The wear resistance of both cast irons in the entire test path is higher after high-temperature quenching with a predominantly metastable dissipative austenite matrix than after conventional quenching with a martensitic matrix (Figs. 3 and 4). This is important for the determination of heat treatment mode, which forms a microstructure with the greatest abrasive wear resistance.

The effective microhardness of the working surfaces of the samples increases in cast iron, which is accompanied by a significant increase in abrasive wear resistance. In terms of the synergetic approach, metastable austenite has the most dynamic structural properties among the structural constituents: adaptatibility, self-reproduction, variability, selection of the most stable structure, and hardenability [4].

CONCLUSIONS

1. The dissipative microstructure of the metal base of the 260Kh16M2 and 250Kh25MFT chromium-containing cast irons consists of martensite and a large amount of metastable retained austenite, with a high friction-hardening ability. The dissipative microstructure is formed by quenching with heating to temperatures of 1125-1170 °C. Such hardening provides increased abrasive wear resistance in comparison with quenching from ordinary temperatures (900-1040 °C), despite higher initial hardness in the second case.

2. Maximum wear resistance of cast irons is ensured by the greatest microhardness ($H_{50} \geq 11$ GPa) formed during the wear process, due to the transformation of the retained austenite into strain-induced martensite on the working surface during the wear process.

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